DSN/Flight Project
Interface Design

CMD-10, Rev. C
DSN Command System

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Contents

Illustrations

Tables

1. Introduction

1.1 Purpose

This module describes the capabilities of the DSN Command System (CMD) as installed at the Deep Space Communications Complexes (DSCCs). It is intended to provide sufficient information to enable telecommunications engineers to predict command system performance when using the DSN Command System.

1.2 Scope

This module provides the performance parameters of the DSN Command system used with all DSN subnets. This module does not provide the capabilities of elements of the DSN Command system which are common to other systems. Information on common elements can be found in module TCI-10 for the 70-m subnet, module TCI-20 for the 26-m subnet, module TCI-30 for the 34-m Standard (STD) and High Efficiency (HEF) subnets, module TCI-31 for the 34-m Beam Waveguide (BWG) and High-speed BWG (HSB) antennas, and module TCI-60 for the 9-m antenna.

2. General Information

The DSN Command System provides the capability for commanding five spacecraft from the Canberra and Madrid DSCCs. A minimum of two of these must be deep space spacecraft and a maximum of four can be deep space spacecraft. A minimum of one of the spacecraft must be an earth orbiter and a maximum of three can be earth orbiters.

The presence of an additional set of command equipment and several additional antennas at the Goldstone DSCC permits six spacecraft to be commanded.. A minimum of two of these must be deep space spacecraft and a maximum of five can be deep space spacecraft. A minimum of one of the spacecraft must be an earth orbiter and a maximum of four can be earth orbiters.

All commands, including prefix symbols and command data symbols, are normally generated at the appropriate Mission Operations Center (MOC) or Project Operations Center (POC). A limited number of pre-defined commands may be stored at the DSCCs for use in an emergency (such as loss of communication from an operations center during a critical mission event) to place a spacecraft in a safe condition.

2.1 Power Output

The DSN Command System is capable of providing a single uplink channel from each antenna for earth orbiter or deep space support. The available power output depends on the frequency range and antenna type as described below.

2.1.1 Earth Orbiter S-band

The maximum total power output available for single-channel command modulation in the 2025-2070 MHz band or the 2090-2108 MHz band is +73 dBm (20 kW) at the output of the transmitter in the 34-m STD (DSS 42 and 61) or 34-m BWG (DSS 24, 34, and 54) subnets. The output of the transmitter in both subnets is restricted to +67 dBm (5 kW) in the 2070-2090 MHz frequency band.

The nominal total power output available at the 9-m antenna (DSS 17) and the 26-m antennas (DSS 16, 46, and 66) is +73 dBm (20 kW). However, when an adequate uplink margin exists, the 9-m and 26-m antenna power amplifiers are normally operated at about +63 dBm (2 kW) to extend klystron life. A power amplifier bypass mode providing +42 dBm (16 W) output power is also available.

The nominal total power output available at the 34-m HSB antenna (DSS 27) is +53 dBm (200 W) using a solid-state power amplifier.

The 9-m, 26-m, 34-m STD, and 34-m BWG subnets employ a step-tuned transmitter with a 20-MHz bandwidth and a 5-MHz overlap for each step in order to provide the specified frequency coverage.

2.1.2 Deep Space S-band

The maximum total power output available for single-channel command modulation in the 2110-2120 MHz band is +73 dBm (20 kW) at the output of the transmitter in the 34-m STD (DSS 42 and 61), 34-m BWG (DSS 24, 34, and 54), and the low-power transmitter in the 70-m subnet (DSS 14, 43, and 63). At the 70-m antennas, an additional transmitter with a nominal power output of +86 dBm (400 kW) is available for linking to very distant planetary spacecraft or for support during spacecraft emergencies. The remaining two 34-meter BWG antennas (DSS 25 and 26) and the 34-m HSB antenna do not have a 2110-2120 MHz uplink capability.

2.1.3 Deep Space X-band

The nominal total power output available for single-channel command modulation in the 7145-7190 MHz band is +73 dBm (20 kW) at the output of the transmitter in the 34-m high-efficiency (HEF) subnet (DSS 15, 45, and 65) and +66 dBm (4 kW) at the output of the transmitter in the 34-m BWG antennas (DSS 25, 26, 34, and 54). The remaining subnets, the BWG antenna, DSS 24, the 9-m antenna (DSS 17), and the 34-m HSB antenna (DSS 27) do not have a 7145-7190 MHz uplink capability.

2.2 Modulation Modes

The DSN Command System produces a pulse code modulated (PCM) non-return to zero-level (NRZ-L) data waveform. Manchester (Bi-phase-L) encoding is available providing a transition for each bit, i.e., 01_2 for a command bit *zero* and 10_2 for a command bit *one*.

The resultant waveform is used to modulate a subcarrier in the binary phase shift keyed (PSK) mode or to alter the frequency of a subcarrier in the frequency shift keyed (FSK) mode. If required for project support, the modulated subcarrier can be either linearly summed with the data clock (PCM/PSK - SUMMED or PCM/FSK - SUMMED) or amplitude modulated by it (PCM/PSK - AM and PCM/FSK - AM). At the 26-meter stations, the capability exists to use the composite PSK waveform to frequency modulate a 70 kHz subcarrier (PCM/PSK - SUMMED/FM and PCM/PSK - AM/FM).

2.3 Subcarrier Frequencies

2.3.1 PSK Subcarrier Frequencies

PSK subcarrier frequencies are available in the range of 100 Hz to 16 kHz with a resolution of 0.1 Hz and can be either sine wave or square wave. The NASA Planetary Program Flight/Ground Data System Standards recommend, and all NASA Standard Transponders require, a 16-kHz sine wave subcarrier.

2.3.2 FSK Subcarrier Frequencies

The two values for the FSK subcarrier frequencies must be selected from the range of 100 Hz to 16 kHz and have a resolution of 0.1 Hz. FSK subcarriers are always sine wave.

2.3.3 Stability

The stability of the PSK subcarrier or of the two values for the FSK sub-carrier is determined by the station frequency standard and is, therefore, better than ±1 part in 10^7 for all measurement times.

2.4 Data Rates

Command bit rates can be specified to 5 significant figures (e.g., 7.8125 or 1000.0).

2.4.1 PSK Data Rates

PSK data rates are available from 1 b/s to 2000 b/s, provided that the data rate multiplied by an even integer yields the subcarrier frequency. Data symbol zero crossings are coincident within ±6° of the subcarrier zero crossings.

Manchester (Bi-phase-L) encoding is available for data rates up to and including 1000 b/s giving two symbols for each bit, i.e., 01_2 for a command bit *zero* and 10_2 for a command bit *one*.

2.4.2 FSK Data Rates

FSK data rates are available from 1.0 b/s to 2000 b/s. FSK modulation is continuous phase so the change from one subcarrier frequency to the other occurs at the next zero crossing after the data transition.

2.4.3 Data Rate Stability

The stability of the selected data rate is determined by the station frequency standard and is, therefore, better than ±1 part in 10^7 for all measurement times.

2.5 Subcarrier to Data Rate Ratios

The subcarrier to data symbol rate ratio must be ≥ 8 for both PSK and FSK (using the lower of the two subcarrier frequencies, f_0) data modes. This ratio is necessary to allow adequate time to complete all parameter verifications within one command symbol interval, i.e., for completion of all checks associated with the current symbol before the start of the next symbol.

2.6 Clock Modulation and Summing

The PSK or FSK subcarrier can be amplitude modulated at the data clock frequency or linearly summed with the data clock. The phase offset between the data transitions and the clock may be set at 0, 90, 180, or 270°. The accuracy of the phase offset is within ±6-degrees of the selected value.

2.6.1 Amplitude Modulation

The amount by which the clock modulates the PSK or FSK subcarrier can be adjusted from 10 to 90 percent with a resolution of 10 percent. The accuracy of the modulation level is ±5 percent of the selected value. An illustration of clock amplitude modulation is shown in Figure 1.

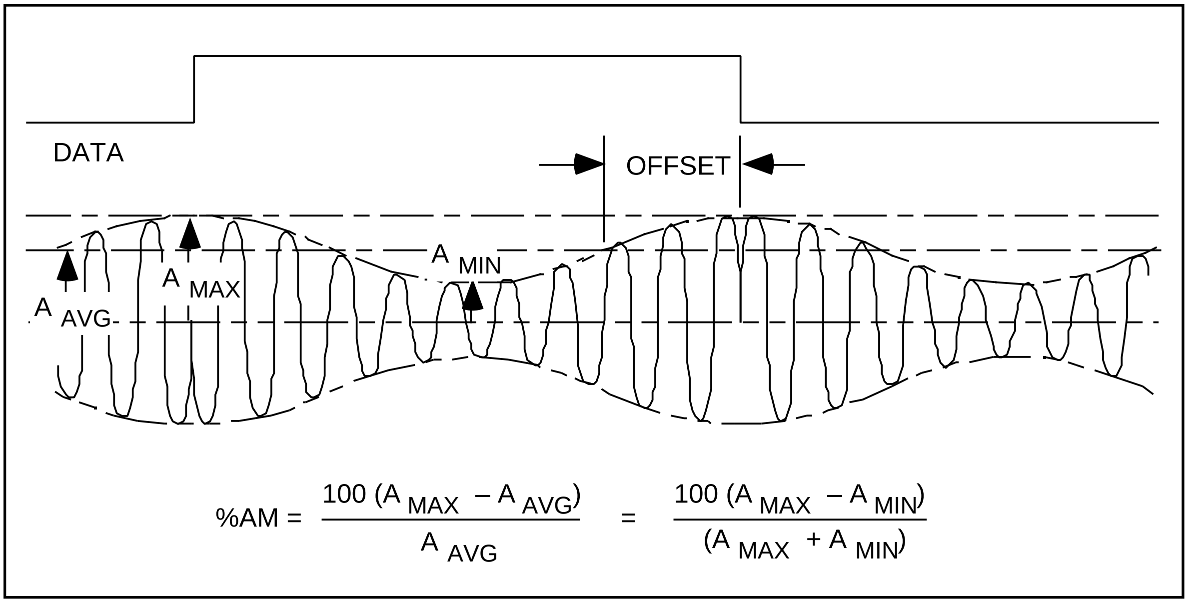

Figure 1. Amplitude Modulation of Subcarrier by Clock Frequency.

2.6.2 Clock Summing

The ratio by which the clock can be summed with the PSK or FSK subcarrier is set at 1:1 with an accuracy of ±5 percent. An illustration of clock summing is shown in Figure 2.

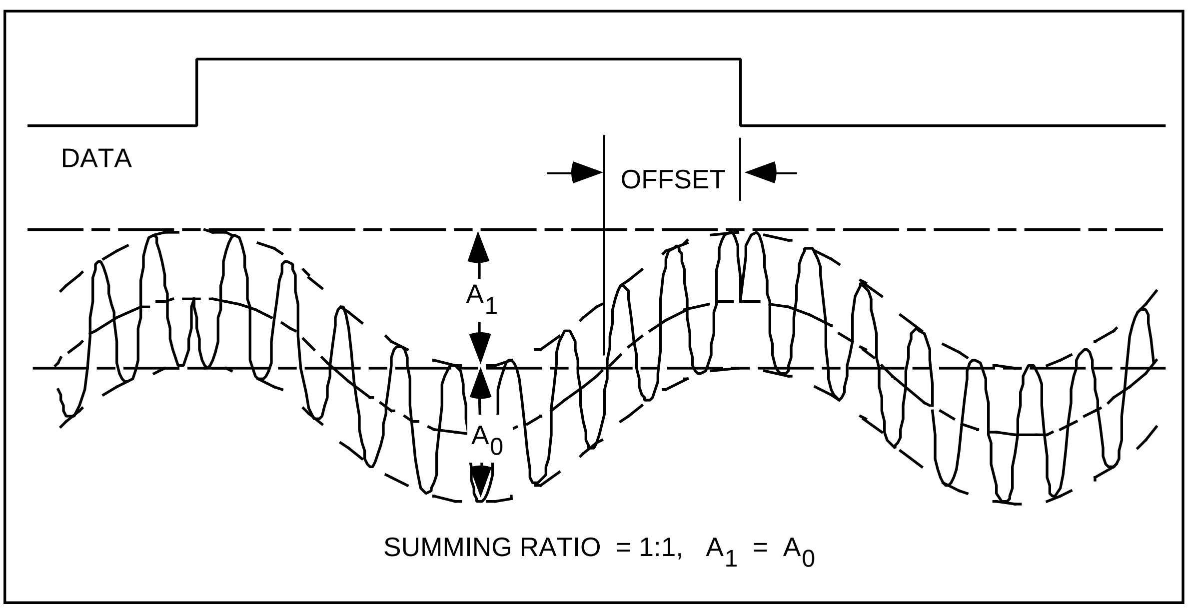

Figure 2. Summing of Subcarrier and Clock Frequency.

2.7 Frequency Modulation

When the composite PSK subcarrier is used to frequency modulate a 70-kHz subcarrier, the deviation is 5 kHz ±TBS.

2.8 Modulation Index

2.8.1 Range

The RF carrier may be phase-modulated at modulation indices from 0.3 to 1.57 rad (peak) for sine-wave or square-wave subcarriers. Pre calibrations can be provided for up to four modulation index settings per spacecraft. The modulation index for X-band carriers must be limited to 1.4 rad (peak) if verification feedback from the exciter to the command modulator (long-loop verification) is used.

2.8.2 Accuracy and Resolution

The modulation index can be set in increments of 0.009 radian (approximately 0.5°) over the range specified above. However, the method of measurement used to set the modulation index limits the calibration accuracy to ±0.1 dB (carrier suppression) for modulation indices of 0 to 3.0 dB (carrier suppression) and ±0.2 dB for modulation indices in excess of 3.0 dB. Carrier power suppression and data power suppression as functions of modulation index angle are:

1. Sinewave subcarrier:

$$\frac{P_C}{P_T}(dB) = 10\log\left[J_0^2(\Theta_D)\right]$$

$$\frac{P_D}{P_T}(dB) = 10\log\left[2J_1^2(\Theta_D)\right] \quad \{\textit{first upper and lower sidebands}\}$$

2. Square-wave subcarrier:

$$\frac{P_C}{P_T}(dB) = 10\log\left[\cos^2(\Theta_D)\right]$$

$$\frac{P_D}{P_T}(dB) = 10\log\left[\sin^2(\Theta_D)\right] \quad \{\textit{all sidebands}\}$$

where:

Θ_D = data modulation index, radians, peak

P_T = total power

P_C = carrier power

P_D = data power

J_0 = zero-order Bessel function

J_1 = first-order Bessel Function

2.8.3 Modulation Index Stability

The modulation index stability is the product of the stability of the command modulator output voltage and the exciter phase modulator input-voltage sensitivity.

- Command modulator output voltage stability is ±3% in 24 hours.
- Exciter phase modulator input voltage sensitivity is ±1% in 24 hours.

2.9 Modulation Losses

Modulation losses due to transmitter bandpass limiting in the S-band transmitters of the 26-meter, 34-meter STD, 34-m BWG, and the 9-meter antennas are eliminated through the use of a tunable klystron power amplifier.

Modulation losses due to transmitter bandpass limiting in the 34-meter HEF and 70-meter subnet transmitters are negligible over the deep space uplink allocation and can be eliminated for all permissible subcarriers by output tube selection.

Modulation losses due to transmitter bandpass limiting in the solid-state transmitters at the 34-meter BWG stations are negligible.

2.10 Deep Space Store-and-Forward Command Protocol

2.10.1 Command Data Handling

The DSN Command System design allows the Flight Project Mission Operations Center (MOC) to prepare large files of spacecraft commands in advance and forward several files to the DSCC for use during a spacecraft track. Each file may contain up to 256 blocks, where the first block is a header element and the remaining blocks are command elements. Each command element may contain up to 800 bits of spacecraft command data. A maximum of eight files can be stored at the DSCC for a given mission. Thus, the maximum storage capability may be described by any one of the following:

- 8 command files
- 8 x 255 = 2040 command elements
- 2040 x 800 = 1,632,000 command bits

After being loaded in the CPA, the files may be selected from the directory for assignment to the radiation queue. This process is called *attaching*. A five-entry queue of file names is provided. Files are attached to the end of the queue. A file must be *closed* to be eligible for attachment. The file directory status and queue status are recallable by the MOC for verification. Capabilities also exist for clearing of the file queue and for erasing individual files from the directory.

2.10.2 Execution of Timed Commands

The Store-and-Forward protocol provides the user with an option to specify the time at which the first bit in each command file is radiated. When this option is used, the desired bit-1 time is specified in tenths of seconds from the start of the calendar year (UTC). Since command radiation is controlled by a bit rate clock, the actual time of command transmission varies from slightly less than 0.1 s before the specified time to slightly less than two bit periods after the specified time, in accordance with the following rules.

- Data Rates from 1 to 10 b/s. The actual time of transmission occurs no sooner than 0.1 s before the specified time and no later than two bit periods after the specified time.
- Data Rates above 10 b/s. The actual time of transmission occurs no sooner than the specified time and no later than two it periods after the specified time.

The Store-and-Forward protocol also provides the user an option to insert a delay interval between the elements of a command file. When this option is used, a delay time interval is specified in each command element message indicating the number of tenths of seconds desired from the first bit of the previous element. The specified interval must be at least large enough to account for the time required for radiation of the previous element plus 0.3 s or two bit periods, whichever is longer. The actual time interval will be a multiple of the bit period for the data rate of the commands, and may be as much as two bit periods longer than the specified interval. When no delay time is specified in a command element message, the element is radiated contiguously with the previous element.

To improve command execution timing at low bit rates, users are encouraged to synthesize low rates from higher rates; e.g., if each (NRZ-L) data bit is represented by “n” identical bits in a command element, the desired data rate will be achieved by transmitting this element at the desired rate multiplied by n. The result of this will be to improve command execution timing by a factor of n.

2.11 Earth-Orbiter Throughput Command Protocol

A real-time *throughput command* interface is provided for Earth orbiter missions (similar to the interface required for missions supported by the Tracking and Data Relay Satellite System, TDRSS). The throughput command data handling scheme permits the MOC to send command data to the DSCC in sequences of data blocks, each of which may contain up to 4592 b of spacecraft command data. Command radiation begins when the fifth data block or the last block of a shorter sequence is received. (The last block is identified by a 1-b flag in the block header or an elapse of 3 s without receipt of another block.) The relationship between data block size and data rate must be chosen so that each data block, except the last data block, contains at least 1 s of command data.

When the outputting of received blocks has begun, any additional blocks received will be output as soon as possible in a continuous manner. Uplink will continue until all available command data are exhausted. Contiguous command data over block boundaries can be provided, but it is the responsibility of the MOC to generate the appropriate data input rate to ensure that at least four but no more than 20 data blocks are present in the CPA until all contiguous blocks have been sent. (The maximum buffer content in the CPA is 20 blocks.) Deviations between the uplink clock at the station and the serial command generator at the MOC can cause data to be lost (if the MOC clock is faster) or gaps to occur in the uplink (if the station clock is faster). When command data are exhausted, the uplink processor reinstates the criteria described above for initial command radiation.

2.12 Emergency Support

The DSN Command System provides emergency support during communications failures between the control center and the DSCC for the purpose of placing a spacecraft into a safe condition. To support this capability, the Project can provide emergency command data which will be stored at the stations. Emergency command data will be processed under control by the link operator in accordance with Project Instructions.

2.13 Command Data Error Rate

Command data undetected error rate is less than 1 b in 10^6 transmitted bits.

The average command abort rate is less than two aborts per 10^7 transmitted bits. (This mean-time between aborts provides a 95-percent probability of modulating in excess of 2.5×10^5 contiguous bits without aborting.)

2.14 Command Mode

The Command Subsystem at each DSCC has six operating modes: Calibrate 1, Calibrate 2, Idle 1, Idle 2, Active, and Abort. Each of the six command modes is related to a particular phase of the Command Subsystem operation. The command mode is selectable from the MOC when the Command System is operating with the Store-and-Forward protocol. The Calibrate 2 and Idle 1 modes are not available when operating with Throughput protocol and the operating mode must be selected at the DSCC.

Table 1 describes the waveform and transmit capabilities for each mode. The configuration used for each mode is established by the Network Operations Control Center (NOCC) in accordance with flight project requirements. Where idle sequences are permitted, the Idle 1 and Idle 2 symbol patterns may be alike or different, depending on spacecraft requirements.

Table 1. Waveform and Transmit Capabilities.

Mode	Subcarrier	Idle Sequence	Transmitter Required Active?
Calibrate 1	yes	yes	yes (dummy load)
Calibrate 2	no	no	no
Idle 1	optional	optional	optional
Idle 2	optional *	optional *	optional
Active	yes	(command)	yes
Abort	optional	optional	optional

* *Yes, for subsystem self-test*

Input and output messages are permitted or inhibited depending on the particular mode in use, as shown below in Figure 3.

2.15 Idle Sequences

For command operations in either of the two idle modes, the available modulation options are: (a) subcarrier with a locally generated repetitive bit pattern, (b) subcarrier only (unmodulated), and (c) no modulation (carrier only).

2.16 Space Shuttle Commanding

The 26-meter subnet provides Space Shuttle Orbiter command support as described in GSFC Document ME 8043, *Shuttle Forward Link Data System*.

SUBSYSTEM MODE	LEGEND: ❖ Primary Purpose; ■ Message types Accepted via GCF (Recall messages will be accepted when Subsystem is in Local Control); ● Comments
Calibrate 1	❖ Allows DSCC local operations personnel to perform initialization tasks ■ After switch to remote control: Configuration Standards and Limits, Mode Control, Recall Requests ● Upon receipt of a configuration standards and limits block, the Calibrate 2 Mode will be entered
Calibrate 2 Store and Forward Protocol Only	❖ Standard mode for updating Configuration Standards and Limits via GCF prior to spacecraft acquisition ■ Configuration, Configuration Standards and Limits, Mode Control, Command Files, Recall Requests ● Multimission standard procedures should state that this mode is to be entered for changing subcarrier frequency.
Idle 1 Store and Forward Protocol Only	❖ Safe mode - cannot command, allows Configuration Standards and Limits to be changed, permits idle pattern radiation ■ Configuration Standards and Limits, Mode Control, Command Files, Recall Requests ● Multimission standard procedures should state that this mode is to be entered for changing bit rate and modulation index.
Idle 2	❖ Allows automatic entry into the active mode, permits idle pattern radiation during command periods ■ Mode Control, Command Files, Recall Requests ● Subsystem enters this mode between timed command elements
Active	❖ Command radiation ■ Mode Control, Command Files, Recall Requests ● Subsystem is in this mode during command element radiation
Abort	❖ Provides abort instruction to Command Modulator Assembly ■ Mode Control, Command Files, Recall Requests ● Abort mode and be inhibited by Abort Overide Enable

Selectable Abort Return (Standard is Idle 1)

Bit Verify Error

Figure 3. Command Subsystem Modes